7.3 THE SPEED OF SOUND

PRACTICE

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Understanding Concepts

1. (a) $v = 332 \text{ m/s} + \left(0.59 \dfrac{\text{m/s}}{°\text{C}}\right)t$

$= 332 \text{ m/s} + \left(0.59 \dfrac{\text{m/s}}{°\text{C}}\right)(21°\text{C})$

$v = 344 \text{ m/s}$

(b) $v = 332 \text{ m/s} + \left(0.59 \dfrac{\text{m/s}}{°\text{C}}\right)(24°\text{C})$

$v = 346 \text{ m/s}$

(c) $v = 332 \text{ m/s} + \left(0.59 \dfrac{\text{m/s}}{°\text{C}}\right)(-35°\text{C})$

$v = 311 \text{ m/s}$

2. $t = \dfrac{v - 332 \text{ m/s}}{\left(0.59 \dfrac{\text{m/s}}{°\text{C}}\right)}$

3. The time taken for sound to travel 664 m is:

$\Delta t = \dfrac{\Delta d}{v}$

$= \dfrac{664 \text{ m}}{332 \text{ m/s}}$

$\Delta t = 2.0 \text{ s}$

$\text{vibrations} = (440 \text{ Hz})(2.0 \text{ s})$

$= 880 \text{ times}$

4. Given: $t = 30.0°\text{C}$, $d = 200$ m, and $\Delta t = 21.1$ s

By the time the sound from the pistol reaches the timer, the runners would have advanced a certain distance. Thus the time required is less than the time measured by an amount equal to the time the sound takes to reach the timer.

Assume that light travels instantaneously over a short distance of 200 m (a valid assumption). First, find the speed of sound:

$v = 332 \text{ m/s} + \left(0.59 \dfrac{\text{m/s}}{°\text{C}}\right)t$

$= 332 \text{ m/s} + \left(0.59 \dfrac{\text{m/s}}{°\text{C}}\right)(30.0°\text{C})$

$v = 350 \text{ m/s}$

$\Delta t = \dfrac{\Delta d}{v}$

$= \dfrac{200 \text{ m}}{350 \text{ m/s}}$

$\Delta t = 0.57 \text{ s}$

The new time is 21.1 s – 0.57 s = 20.5 s.

Activity 7.3.1 Measuring the Speed of Sound Outside

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The speed of sound is determined in this activity by setting up a rhythmic clap of two boards being struck together and listening for the echo between claps. For the purposes of this investigation it is assumed that the distance between the source of sound and the reflecting wall is 150.0 m. Students time how long 20 “clap intervals” take and then find the average interval between claps. The sound has travelled four times the distance between observer and wall (600.0 m) in this interval. The speed of sound is calculated and compared with the expected speed when the temperature is taken into account.

Assuming the temperature is 20°C, the expected speed of sound will be

$$v = 332\text{m/s} + \left(0.59\frac{\text{m/s}}{^{\text{o}}\text{C}}\right)t$$

$$= 332 \text{ m/s} + \left(0.59\frac{\text{m/s}}{^{\text{o}}\text{C}}\right)(20^{\text{o}}\text{C})$$

$$v = 343.8 \text{ m/s}$$

If the average "clap interval" is found to be 1.75 s, this would result in a calculated speed of:

$$v = \frac{d}{t}$$

$$= \frac{600.0 \text{ m}}{1.75 \text{ s}}$$

$$v = 342.9 \text{ m/s}$$

The percentage error associated with this value is then calculated as:

$$\%\text{ error} = \frac{|\text{experimental} - \text{accepted}|}{\text{accepted}} \times 100\%$$

$$= \frac{|342.9 \text{ m/s} - 343.8 \text{ m/s}|}{343.8 \text{ m/s}} \times 100\%$$

$$= 0.262\% \text{ (three significant digits allowed)}$$

Investigation 7.3.1 Measuring the Speed of Sound in the Classroom

(Pages 244–245)

Materials and Equipment

- sound sensor and interface
- air column closed at one end

Observations

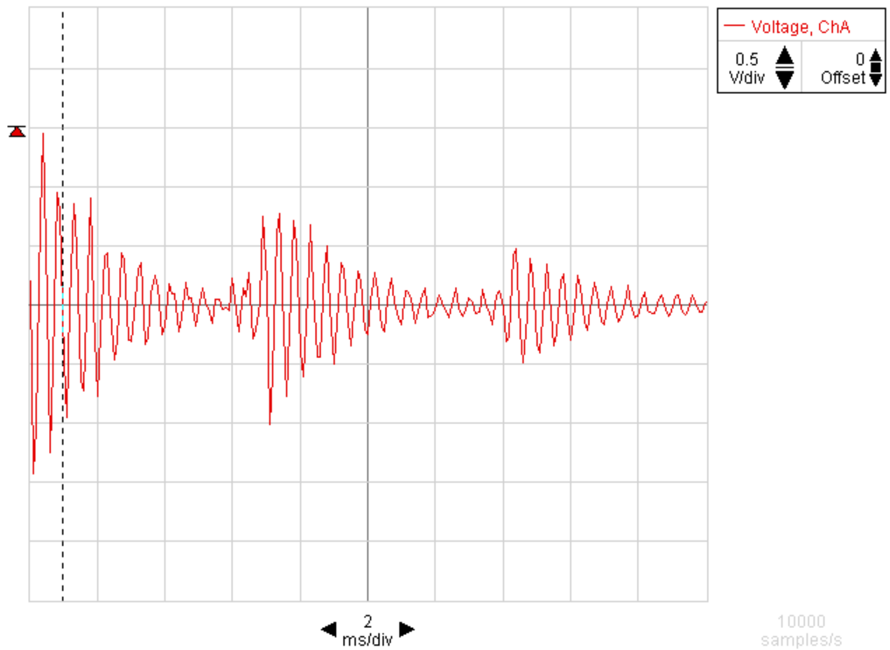

Figure 1
Oscilloscope trace for sound

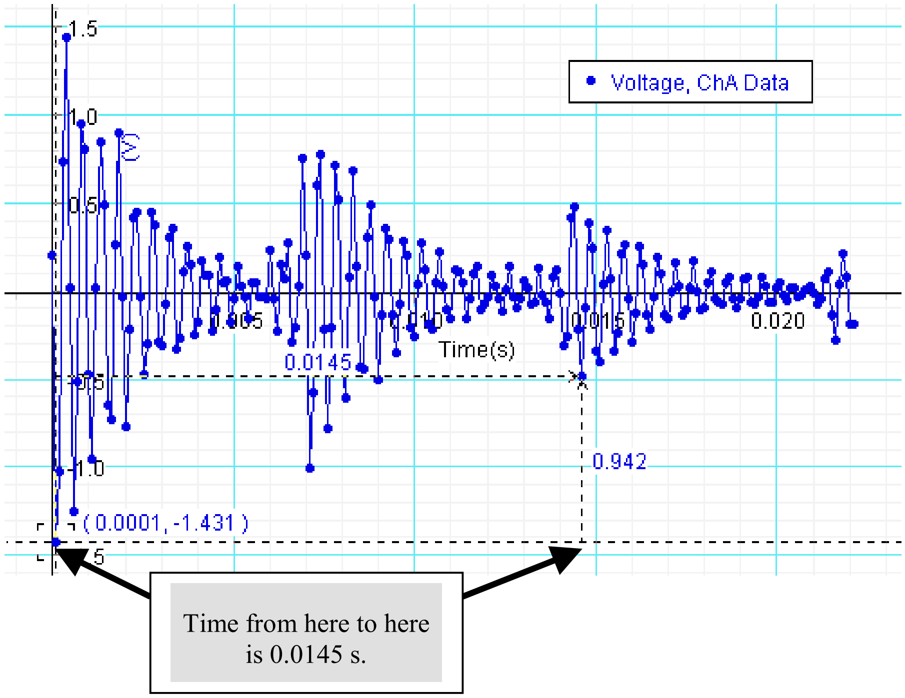

Figure 2
Graph display for oscilloscope trace

Analysis

(b)–(c) Temperature of the air in the room is 18°C. The accepted value for the speed of sound is given by

$$v = 332\ \text{m/s} + \left(0.59\ \frac{\text{m/s}}{\text{C}^\circ}\right)t$$

$$= 32\ \text{m/s} + 0.59\ \frac{\text{m/s}}{\text{C}^\circ}(18^\circ\text{C}) \qquad \text{temperature of the air in the room} = 18^\circ\text{C}$$

$$v = 343\ \text{m/s}$$

The predicted speed of sound in air would be 343 m/s.

length of air column = 245 cm or 0.245 m

distance travelled by sound = 2 × 0.245 m = 4.90 m

$$v = \frac{\Delta d}{\Delta t}$$

$$= \frac{4.90\ \text{m}}{0.0145\ \text{s}}$$

$$v = 338\ \text{m/s}$$

The measured speed of sound in air was 338 m/s.

Evaluation

(d) The difference between the predicted and measured speed of sound was 5 m/s.

The percentage difference was $\dfrac{-5\ \text{m/s}}{338\ \text{m/s}} \times 100\% = -1.5\%$.

(e) Since the measurement was taken to the nearest mm and the timing was accurate to 4 significant figures, we must look elsewhere for sources of error. Another area to examine is the temperature of the air, which would affect the prediction,

There could have been some difference between the temperature in the air of the room and the temperature inside the column. Also, the humidity of the air may affect the speed, since this measurement was made in the summer.

(f) By placing the air column in an enclosed space so there are no air currents and with the thermometer in the air column, the results could be improved.

Synthesis

(g) Follow these steps:
1. Fill the tube with carbon dioxide, using dry ice.
2. Since carbon dioxide is denser than air, the column should be mounted vertically.
3. A splint test could be used to ensure that the column is filled.
4. Repeat the same procedure and calculate the speed of sound.
5. Compare your result with that supplied by your instructor.

(h) Sound must be reflected from the end of the piece of wood.
1. Select a plank or lab desk that is relatively thick
2. Fix the sound sensor to the end of the lab desk with duct tape.
3. With a hammer, sharply strike the end of the wood.
4. Do a number of trials so you get clear readings for the time interval taken between the sound and the return of the echo.
5. Measure the length if the wood.
6. Calculate the speed of sound in wood.

Section 7.3 Questions

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Understanding Concepts

1. $$\begin{aligned} v &= 332 \text{ m/s} + \left(0.59 \frac{\text{m/s}}{°\text{C}}\right)t \\ &= 332 \text{ m/s} + \left(0.59 \frac{\text{m/s}}{°\text{C}}\right)(30.0°\text{C}) \\ v &= 349.7 \text{ m/s or } 3.5 \times 10^2 \text{ m/s} \end{aligned}$$

$$\begin{aligned} \Delta t &= \frac{\Delta d}{v} \\ &= \frac{1.4 \times 10^3 \text{ m}}{3.5 \times 10^2 \text{ m/s}} \\ \Delta t &= 4.0 \text{ s} \end{aligned}$$

2. (a) $$\begin{aligned} v &= 332 \text{ m/s} + \left(0.59 \frac{\text{m/s}}{°\text{C}}\right)t \\ &= 332 \text{ m/s} + \left(0.59 \frac{\text{m/s}}{°\text{C}}\right)(22°\text{C}) \\ v &= 344.9 \text{ m/s or } 345 \text{ m/s} \end{aligned}$$

(b) $$\begin{aligned} \lambda &= \frac{v}{f} \\ &= \frac{345 \text{ m/s}}{380 \text{ Hz}} \\ \lambda &= 0.91 \text{ m} \end{aligned}$$

3. (a) $$\begin{aligned} \Delta t &= \frac{\Delta d}{v}, \text{where } v \text{ is } 5104 \text{ m/s in aluminum at } 0°\text{C} \\ &= \frac{2.0 \times 10^3 \text{ m}}{5104 \text{ m/s}} \\ \Delta t &= 0.39 \text{ s} \end{aligned}$$

(b) $$\begin{aligned} \Delta t &= \frac{\Delta d}{v}, \text{ where } v \text{ is } 1270 \text{ m/s in hydrogen at } 0°\text{C} \\ &= \frac{2.0 \times 10^3 \text{ m}}{1270 \text{ m/s}} \\ \Delta t &= 1.6 \text{ s} \end{aligned}$$

4. $\Delta t = \dfrac{\Delta d}{v}$

v is 5050 m/s in steel at 0°C.

$$\Delta t_{\text{steel}} = \frac{6.0\times10^2 \text{ m}}{5050 \text{ m/s}}$$

$$\Delta t_{\text{steel}} = 0.12$$

v is 332 m / s in air at 0°C.

$$\Delta t_{\text{air}} = \frac{6.0\times10^2 \text{ m}}{332 \text{ m/s}}$$

$$\Delta t_{\text{air}} = 1.8 \text{ s}$$

The time it takes sound to travel in steel is $\dfrac{0.12\text{ s}}{1.8\text{ s}} = \dfrac{1}{15}$ as long as the time it takes sound to travel in air. Note that the same ratio can be found by dividing the speed of sound in air by the speed of sound in steel.

5. $\Delta t = \dfrac{\Delta d}{v}$

$$= \frac{100.0 \text{ m}}{350 \text{ m/s}}$$

$$\Delta t = 0.29 \text{ s}$$

6. $v = 332 \text{ m/s} + \left(0.59 \dfrac{\text{m/s}}{°\text{C}}\right)t$

$$= 332 \text{ m/s} + \left(0.59 \frac{\text{m/s}}{°\text{C}}\right)(20°\text{C})$$

$$v = 344 \text{ m/s}$$

$$\Delta d = v\Delta t$$

$$= (344 \text{ m/s})(10.0 \text{ s})$$

$$\Delta d = 3.44\times10^3 \text{ m}$$

7. $v = \dfrac{\Delta d}{\Delta t}$

$$= \frac{5.0\times10^2 \text{ m}}{1.5 \text{ s}}$$

$$v = 3.3\times10^2 \text{ m/s}$$

8. (a) The frequency of the tuning fork in water at 25°C would be the same (400.0 Hz).
In water at 25°C,

$\lambda = \dfrac{v}{f}$, where v is 1493 m / s at 25°C.

$$= \frac{1493 \text{ m/s}}{400.0 \text{ Hz}}$$

$$\lambda = 3.73 \text{ m}$$

(b) The frequency of the tuning fork in air at 25°C would be the same (400.0 Hz).

$$v = 332 \text{ m/s} + \left(0.59 \frac{\text{m/s}}{°\text{C}}\right)t$$

$$= 332 \text{ m/s} + \left(0.59 \frac{\text{m/s}}{°\text{C}}\right)(25°\text{C})$$

$$v = 347 \text{ m/s}$$

$$\lambda = \frac{v}{f}$$

$$= \frac{347 \text{ m/s}}{400.0 \text{ Hz}}$$

$$\lambda = 0.87 \text{ m}$$

Making Connections

9. In the parade the marchers closest to the band hear the band's beat before the marchers at the end of the parade hear it. Thus, they will tend to "step" sooner that those at the end of the parade.

Reflecting

10. Usually the wind will affect the speed of sound. If the wind is blowing in the same direction as the sound, the sound travels faster. If the wind is blowing in the opposite direction, the sound travels slower.